

CLAIMS

1. (currently amended) A method of reducing metal oxide material to metal comprising the steps of:-

- (i) introducing a mixed composite charge of a metal oxide and a carbonaceous reductant onto the surface of the first carrier material in a multi-loop melt circulation system employing two or more inter-connected loops in which the first carrier material is circulating in a closed loop expressly for the purpose of transporting the charge and reaction products in the solid state through an extended path in contact with the carrier material, which provides the endothermic heat requirements for chemical reactions to take place by direct contact or via gaseous intermediates within the layer of composite charge materials, but itself does not participate chemically to any major extent in the reduction process, all the time coal volatiles and other gaseous products being released into the gas space without major combustion taking place as the charge layer floats along the length of the reduction arm of the melt circulation loop, which is enclosed by walls and a roof of thermal insulating materials;
- (ii) reducing the metal oxide to solid metal by the carbonaceous reductant contained within the floating layer of solids in the reduction zone, the metal oxide and carbonaceous reductant being introduced in proportions such that the carbon from the carbonaceous reductant is converted to carbon monoxide, hydrogen gas also being produced;
- (iii) maintaining a shallow depth of the first carrier material between the melt circulation loop and the second carrier material circulating in a second closed loop serially through a melting zone and a desulphurisation/decarburization zone referred to as the refining loop, so that the metallised raft can subsequently float on the first carrier material and be transferred to the refining loop by drag forces exerted by the first carrier material;
- (iv) separating a metallised raft containing the solid metal from the molten carrier material by projecting the metallised raft into the refining loop upstream of the heating zone of the solid-state reduction loop so that the surface of the first molten carrier material which is circulated to the heating zone is substantially free of solid material;
- (v) mixing the carbon monoxide and hydrogen formed in step (ii) and partially combusting the mixture in the melt refining loop in order to satisfy the thermal requirements for melting the metallised raft and for the chemical reactions taking

- place in the desulphurisation/decarburization zone and providing partially combusted gas containing no free oxygen as required to effect decarburization;
- (vi) optionally carrying out further partial combustion of the carbon monoxide and hydrogen to melt solid scrap or direct reduced material;
 - (vii) after steps (v) and (vi), mixing the carbon monoxide and hydrogen with oxygen and completely combusting the mixture well above the melt in the post combustion arm of the first loop or the solid-state reduction loop so that although direct flame impingement is facilitated, no unreacted oxygen comes into contact with the melt in providing the full thermal requirements for reduction of the oxide charge materials in the solid state by heat transfer to the first molten carrier material which is recirculated to the solid-state reduction zone;
 - (viii) submitting the carbon monoxide and hydrogen to hot gas cleanup for removal of sulphur and solid particulates prior to step (v), (vi) and (vii);
 - (ix) melting the metallised raft in the melting zone of the refining loop and refining the molten metal in the desulphurisation/decarburization zone, and
 - (x) removing the metal so refined from the refining loop.

2. (original) The method as claimed in claim 1, wherein the composite charge additionally comprises a flux.

3. (original) The method as claimed in claim 2, wherein said flux is selected from lime, limestone and dolomite.

4. (original) The method as claimed in claim 1, wherein said metal oxide is selected from one or more of iron, chromium, nickel and manganese oxides.

5. (currently amended) The method as in claim 1, wherein the composite charge added forms a layer having a thickness of from 5 cm to 20 cm, preferably 5 cm to 10 cm, on the first carrier material.

6. (currently amended) The method as in claim 1, wherein the composite charge is at least partially compacted.

7. (currently amended) The method as in claim 1, wherein the ratio of carrier material to metal to be produced is from 100:1 to 500:1, preferably 200:1 to 400:1.

8. (currently amended) The method as in claim 1, wherein the charge reduction zone of the solid-state reduction loop is constituted by a first hearth and the desulphurisation/heating zone is constituted by a second hearth, a flowpath being provided between a downstream end of the first hearth and an upstream end of the second hearth and between a downstream end of the second hearth and an upstream end of the first hearth.

9. (currently amended) The method as in claim 1, wherein the melting zone of the refining loop is constituted by a third hearth and the desulphurisation/decarburisation zone is constituted by a fourth hearth, a flowpath being provided between a downstream end of the third hearth and an upstream end of the third hearth and between a downstream end of the fourth hearth and an upstream end of the third hearth.

10. (currently amended) The method as claimed in claim 9, wherein said flowpaths are provided by gas lift pumps or siphons.

11. (currently amended) The method as in claim 1, wherein the velocity of the carbon monoxide produced in step (ii) increases toward the downstream end of the charge reduction zone.

12. (currently amended) The method as in claim 1, wherein hot gas clean up is effected between steps (ii) and (vii).

13. (currently amended) The method as in claim 1, wherein any slag produced in step (ii) is removed from the carrier material before the latter is passed into the desulphurisation/heating zone.

14. (currently amended) The method as in claim 1, wherein step (iv) is achieved by maintaining a shallow depth of the first molten carrier material in a crossover between the melt circulation loop and the refining loop, so that the metallised raft floats on the first molten carrier material and is transferred to the refining loop by drag forces exerted by the first molten carrier material.

15. (currently amended) The method as in claim 1, wherein the metal removed from the refining loop in step (vii) is passed to an additional refining loop for further refining.

CLAIMS

1. A method of reducing metal oxide material to metal comprising the steps of:-
 - (i) introducing a mixed composite charge of a metal oxide and a carbonaceous reductant onto the surface of the first carrier material in a multi-loop melt circulation system employing two or more inter-connected loops in which the first carrier material is circulating in a closed loop expressly for the purpose of transporting the charge and reaction products in the solid state through an extended path in contact with the carrier material, which provides the endothermic heat requirements for chemical reactions to take place by direct contact or via gaseous intermediates within the layer of composite charge materials, but itself does not participate chemically to any major extent in the reduction process, all the time coal volatiles and other gaseous products being released into the gas space without major combustion taking place as the charge layer floats along the length of the reduction arm of the melt circulation loop, which is enclosed by walls and a roof of thermal insulating materials;
 - (ii) reducing the metal oxide to solid metal by the carbonaceous reductant contained within the floating layer of solids in the reduction zone, the metal oxide and carbonaceous reductant being introduced in proportions such that the carbon from the carbonaceous reductant is converted to carbon monoxide, hydrogen gas also being produced;
 - (iii) maintaining a shallow depth of the first carrier material between the melt circulation loop and the second carrier material circulating in a second closed loop serially through a melting zone and a desulphurisation/decarburization zone referred to as the refining loop, so that the metallised raft can subsequently float on the first carrier material and be transferred to the refining loop by drag forces exerted by the first carrier material;
 - (iv) separating a metallised raft containing the solid metal from the molten carrier material by projecting the metallised raft into the refining loop upstream of the heating zone of the solid-state reduction loop so that the surface of the first molten carrier material which is circulated to the heating zone is substantially free of solid material;
 - (v) mixing the carbon monoxide and hydrogen formed in step (ii) and partially combusting the mixture in the melt refining loop in order to satisfy the thermal requirements for melting the metallised raft and for the chemical reactions taking place in the desulphurisation/decarburization zone and providing partially combusted gas containing no free oxygen as required to effect decarburization;

- (vi) optionally carrying out further partial combustion of the carbon monoxide and hydrogen to melt solid scrap or direct reduced material;
- (vii) after steps (v) and (vi), mixing the carbon monoxide and hydrogen with oxygen and completely combusting the mixture well above the melt in the post combustion arm of the first loop or the solid-state reduction loop so that although direct flame impingement is facilitated, no unreacted oxygen comes into contact with the melt in providing the full thermal requirements for reduction of the oxide charge materials in the solid state by heat transfer to the first molten carrier material which is recirculated to the solid-state reduction zone;
- (viii) submitting the carbon monoxide and hydrogen to hot gas cleanup for removal of sulphur and solid particulates prior to step (v), (vi) and (vii);
- (ix) melting the metallised raft in the melting zone of the refining loop and refining the molten metal in the desulphurisation/decarburization zone, and
- (x) removing the metal so refined from the refining loop.

2. The method as claimed in claim 1, wherein the composite charge additionally comprises a flux.

3. The method as claimed in claim 2, wherein said flux is selected from lime, limestone and dolomite.

4. The method as claimed in claim 1, wherein said metal oxide is selected from one or more of iron, chromium, nickel and manganese oxides.

5. The method as in claim 1, wherein the composite charge added forms a layer having a thickness of from 5 cm to 20 cm, preferably 5 cm to 10 cm, on the first carrier material.

6. The method as in claim 1, wherein the composite charge is at least partially compacted.

7. The method as in claim 1, wherein the ratio of carrier material to metal to be produced is from 100:1 to 500:1, preferably 200:1 to 400:1.

8. The method as in claim 1, wherein the charge reduction zone of the solid-state reduction loop is constituted by a first hearth and the desulphurisation/heating zone is constituted by a second hearth, a flowpath being provided between a downstream end of the first hearth and an upstream end of the second hearth and between a downstream end of the second hearth and an upstream end of the first hearth.

9. The method as in claim 1, wherein the melting zone of the refining loop is constituted by a third hearth and the desulphurisation/decarburisation zone is constituted by a fourth hearth, a flowpath being provided between a downstream end of the third hearth and an upstream end of the fourth hearth and between a downstream end of the fourth hearth and an upstream end of the third hearth.

10. The method as claimed in claim 9, wherein said flowpaths are provided by gas lift pumps or siphons.

11. The method as in claim 1, wherein the velocity of the carbon monoxide produced in step (ii) increases toward the downstream end of the charge reduction zone.

12. The method as in claim 1, wherein hot gas clean up is effected between steps (ii) and (vii).

13. The method as in claim 1, wherein any slag produced in step (ii) is removed from the carrier material before the latter is passed into the desulphurisation/heating zone.

14. The method as in claim 1, wherein step (iv) is achieved by maintaining a shallow depth of the first molten carrier material in a crossover between the melt circulation loop and the refining loop, so that the metallised raft floats on the first molten carrier material and is transferred to the refining loop by drag forces exerted by the first molten carrier material.

15. The method as in claim 1, wherein the metal removed from the refining loop in step (vii) is passed to an additional refining loop for further refining.